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Forward Jets at HERA and at the Tevatron

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Abstract

In this talk I consider forward-jet production at HERA and at the Tevatron as a probe of the multiple gluon radiation induced by the BFKL evolution.

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1 Introduction

In DIS at HERA semi-hard processes, for which the squared center-of-mass energy s is much larger than the momentum transfer Q^2, are investigated and values of $x_{bj} = Q^2/s$ of the order of 10^{-5} have been attained [1]. The evolution of the $F_2(x_{bj}, Q^2)$ structure function in $\ln(Q^2)$ is usually described by the DGLAP equation. However, at very small values of x_{bj} we may consider to resum the leading logarithmic (LL) contributions in $1/x_{bj}$ to F_2, by using the BFKL evolution equation [2, 3].

A caveat is in order: the BFKL equation computes the radiative corrections to parton-parton scattering in the high-energy limit, assuming that the outgoing partons are balanced in transverse momentum. Therefore there is no transverse-momentum evolution in the process. It is not possible to assess whether this costraint is fulfilled in the configurations that drive the rise of F_2 at small x_{bj}, but it may be forced upon the DIS process by tagging a jet in the proton direction [4] and by requiring that the squared jet transverse momentum is of the order of Q^2. An analogous process for which the multiple gluon radiation induced by the BFKL evolution may be relevant is dijet production at large rapidity intervals η in $p\,\bar{p}$ collisions [5].

2 Forward jets

In the high-energy limit parton-parton scattering is dominated by gluon exchange in the cross channel, which is typically an $\mathcal{O}(\alpha_s^2)$ process. This occurs at leading order (LO) in dijet production in $p\,\bar{p}$ collisions [6], and at next-to-leading order (NLO) in dijet production with a forward jet in DIS [7] (or at LO in three-jet production [7, 8]). Indeed, in DIS the NLO dijet production and the LO three-jet production turn out to be bigger [7] than the LO dijet production, which is $\mathcal{O}(\alpha_s)$, when a forward jet is required. On top of the cross-channel-gluon dominated processes, the BFKL equation resums the LL contributions, in $\ln(\hat{s}/Q^2)$, to all orders in α_s in the multi-Regge kinematics, which assumes that the outgoing partons are strongly ordered in rapidity η and have comparable transverse momentum. The higher-order corrections to gluon exchange yield a gluon ladder in the cross channel [2]. The leading logarithms are resummed by the function,

$$f(k_{a\perp}, k_{b\perp}, \tilde{\phi}, \eta) = \frac{1}{(2\pi)^2 k_{a\perp} k_{b\perp}} \sum_{n=-\infty}^{\infty} e^{in\tilde{\phi}} \int_{-\infty}^{\infty} d\nu\, e^{\omega(\nu,n)\eta} \left(\frac{k_{a\perp}^2}{k_{b\perp}^2}\right)^{i\nu}, \qquad (1)$$

with $\mathbf{k_{a\perp}}$ and $\mathbf{k_{b\perp}}$ the transverse momenta of the gluons at the ends of the ladder, $\tilde{\phi}$ the azimuthal angle between them, $\eta \simeq \ln(\hat{s}/k_\perp^2)$ an evolution parameter of the ladder required to be large, and $\omega(\nu, n)$ the eigenvalue of the BFKL equation whose maximum $\omega(0,0) = 4\ln 2 N_c \alpha_s/\pi$ yields the known power-like growth of f in energy [2].

In inclusive dijet production in $p\,\bar{p}$ collisions the resummed parton cross section is [5,

9],

$$\frac{d\hat\sigma}{dk_{a\perp}^2 dk_{b\perp}^2 d\phi} = \frac{\pi N_c^2\alpha_s^2}{2k_{a\perp}^2 k_{b\perp}^2}\, f(k_{a\perp}^2, k_{b\perp}^2, \tilde\phi, \eta)\,, \tag{2}$$

with ϕ the azimuthal angle between the tagging jets, $\phi = \tilde\phi + \pi$. At the hadron level, η is the rapidity difference between the tagging jets, $\eta = \eta_{j_1} - \eta_{j_2}$, and accordingly evidence of the BFKL dynamics is searched in dijet events at large rapidity intervals [10].

In forward-jet production in DIS in the lab frame the lepton-parton cross section is [4, 8, 11]

$$\frac{d\hat\sigma}{dydQ^2dk_\perp^2 d\phi} = \sum_q e_q^2 \frac{N_c\alpha^2\alpha_s^2}{\pi^2(Q^2)^2 k_\perp^2 y} \int \frac{dv_\perp^2}{v_\perp^2} f(v_\perp^2, k_\perp^2, \tilde\phi, \eta)\mathcal{F}(v_\perp^2, Q^2, \hat\phi, y)\,, \tag{3}$$

with y the electron energy loss; Q^2 the photon vituality; the function $\mathcal{F}$ accounting for the $q\,\bar q$ pair that in the high-energy limit mediates the scattering between the photon and the cross-channel gluon; $k_\perp$ and $v_\perp$ respectively the transverse momenta of the forward jet and of the gluon attaching to the $q\,\bar q$ pair; $\hat\phi$ the azimuthal angle between the photon and the gluon; ϕ the azimuthal angle between the outgoing electron and the jet, with $\phi = \hat\phi + \tilde\phi + \pi$; and with the sum over the quark flavors in the $q\,\bar q$ pair. η is then related to x_{bj} and to the momentum fraction x of the parton initiating the hard scattering within the proton through $\eta = \ln(x/x_{bj})$. Producing the jet forward ensures that x is not small; η is then made large by selecting events at small x_{bj}.

The BFKL ladder f (1) induces a strong enhancement in the parton cross sections (2) and (3) when η grows [2]. In a hadron collider $\eta = \eta_{j_1} - \eta_{j_2} \simeq \ln(x_1x_2s/k_\perp^2)$. At fixed s, like at the Tevatron, η grows by increasing x_1 and x_2. This introduces a damping in

the production rate, due to the falling parton luminosity [9], and conceals the growth due to f (1). The advantage of HERA is that a fixed-energy ep collider is nonetheless a variable-energy collider in the photon-proton frame [4], thus it is possible to increase $\eta = \ln(x/x_{bj})$ by decreasing x_{bj} while keeping fixed x.

The truncation to $\mathcal{O}(\alpha_s^2)$ of the forward-jet rate derived from eq. (3), which has three final-state partons, corresponds to the lowest-order approximation to the BFKL ladder and is in good agreement with the exact LO three-jet rate with a forward jet [8]. However, the BFKL calculation with the full ladder (1) yields a curve whose normalization is bigger by an order of magnitude, and which grows faster than the $\mathcal{O}(\alpha_s^2)$ evaluations as x_{bj} decreases. The H1-Collaboration data [12] seem to favor the BFKL calculation [8]. This looks encouraging, however as a caveat we recall that in dijet production at the Tevatron a comparison of the $\mathcal{O}(\alpha_s^3)$ matrix elements, exact and in the BFKL approximation, shows that the latter overestimates the available phase space [13].

3 The azimuthal-angle decorrelation

In two-jet production at large rapidity intervals in $p\,\bar{p}$ collisions the BFKL evolution predicts that the ϕ correlation between the tagging jets decreases as the rapidity difference between the tagging jets increases [9]. This phenomenon has been observed by the D0 Collaboration at the Tevatron [10], however, the BFKL ladder yields too much decorrelation while the Monte Carlo JETRAD [14], based on the exact NLO dijet production,

yields too little decorrelation. The data is in good agreement with a simulation from the Monte Carlo HERWIG [15]. This seems to suggest that corrections higher than $\mathcal{O}(\alpha_s^3)$ are needed to describe the data, but not so much of it as contained in the BFKL ladder.

In jet production in DIS we know that at the parton-model level, i.e. at $x = x_{bj}$, the jet and the electron are produced back-to-back, and we expect that when $x > x_{bj}$, but with $\eta = \ln(x/x_{bj})$ still small, the jet production is dominated at the parton level by the photon-gluon fusion diagram, which has two final-state partons and is expected to yield the usual correlation at $\phi = \pi$ between the electron and the parton tagged as the jet. However as η grows the jet production is increasingly dominated by diagrams with three-final state partons and with gluon exchange in the cross channel, and eventually by the higher-order corrections to them induced by the BFKL ladder.

The lowest-order approximation to the BFKL ladder yields a ϕ distribution peaked at $\phi = \pi/2$. Implementing then the full BFKL ladder (1), the ϕ correlation is completely washed out [8]. However, the high-energy limit can not appreciate the transition from a distribution peaked at $\phi = \pi$ at large x_{bj} to one peaked at $\phi = \pi/2$ at small x_{bj}. It was suggested that an exact $\mathcal{O}(\alpha_s^2)$ calculation should see it [11], and indeed it does [8]. It is to be seen if it will also be observed in the data.

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